3 PROPERTIES, PRODUCTION, AND POTENTIAL FOR EXPOSURE

3.1 CHEMICAL AND PHYSICAL PROPERTIES OF COAL MINE DUST

3.1.1 Coal and Its Characteristics

Coal is a combustible, carbonaceous, sedimentary rock that is formed by the accumulation, compaction, and physical and chemical alteration of vegetation [Simon and Hopkins 1981; Bates and Jackson 1987]. Coal is classified according to its type, grade, and rank. The *type* of coal relates to the plant materials from which the coal originated. The *grade* of coal refers to the purity of the coal—or the amount of inorganic material (including ash and sulfur) left after the coal is burned [Bates and Jackson 1987; Stefanko 1983]. The *rank* of coal indicates its degree of metamorphosis and roughly correlates to the geological age of the coal or the geological environment from which it has been mined [Bates and Jackson 1987]. Rank also indicates the percentage of carbon in dry, mineral-free coal [Whitten and Brooks 1973] and the degree to which the coalification process has progressed [Larsen 1981]. The geological process of coalification begins with organic materials (e.g., celluloses, lignins, and other plant compounds that are deoxygenated and then dehydrogenated) and ends with coal of various geological ages, from lignite to anthracite [Larsen 1981]. Table 3-1 presents the American Society for Testing and Materials (ASTM) classification of coals by rank. According to Parkes [1982], high-rank coal includes anthracite and semianthracite coal ("hard coal," with 91% to 95% carbon); intermediate-rank coal includes low-, medium-, and high-volatile bituminous and sub-bituminous coal ("soft coal," with 76% to 90% carbon); and low-rank coal includes lignite (with 65% to 75% carbon or less). The rank of coal tends to increase from the western to the eastern United States, with anthracite occurring primarily in eastern Pennsylvania [Schlick and Fannick 1971]. Most of the coal currently mined in the United States is bituminous [Given 1984]. A classification of the coal in the United States is provided in Table 3-2.

3.1.2 Composition of Coal Mine Dust

Coal mine dust is a complex and heterogeneous mixture containing more than 50 different elements and their oxides [Coates 1981; Larsen 1981]. The mineral content varies with the particle size of the dust and with the coal seam [Stobbe et al. 1990]. Common minerals associated with coal mine dust include kaolinite, illite, calcite, pyrite, and quartz [Stobbe et al. 1990]. The sulfur content varies from 0.5% (by weight) to more than 10%, with coal from the western United States generally having lower sulfur content [Coates 1981].

Airborne respirable dust in underground coal mines has been estimated to be 40% to 95% coal; the remaining portion consists of a variable mixed dust that is generated from fractured rock on the mine roof or floor, or that is encountered within the coal seam [Kim 1989]. The coal component of respirable dust at surface coal mines can be even more variable, depending on the stage of the mining operation.

Table 3–1. ASTM classification of coals by rank

Coal rank and group	Basis of classification: % fixed carbon (range)*	Basis of classification: Heat content in Btu/lb (range)†	Agglomerating character
Anthracitic:			
Meta-anthracite	98	——	Nonagglomerating
Anthracite	92–<98	——	Nonagglomerating
Semianthracite‡	86–<92	——	Nonagglomerating
Bituminous:			
Low-volatile bituminous	78–<86	——	Commonly agglomerating§
Medium-volatile bituminous	69–<78**	——	Commonly agglomerating§
High-volatile A bituminous	<69**	——	Commonly agglomerating§
High-volatile B bituminous	——	13,000–<14,000	Commonly agglomerating§
High-volatile C bituminous	——	11,500–<13,000	Commonly agglomerating§
High-volatile C bituminous	——	10,500–<11,500	Agglomerating
Sub-bituminous:			
Sub-bituminous A	——	10,500–<11,500	Nonagglomerating
Sub-bituminous B	——	9,500–<10,500	Nonagglomerating
Sub-bituminous C	——	8,300–<9,500	Nonagglomerating
Lignitic:			
Lignite A	——	6,300–<8,300	Nonagglomerating
Lignite B	——	<6,300	Nonagglomerating

Sources: ASTM [1993]; EIA [1993].

*Percentages are based on dry, mineral-matter-free coal. Volatile matter (not shown) is the complement of fixed carbon; that is, the % fixed carbon and % volatile matter is 100%. As % fixed carbon decreases, % volatile matter increases by the same amount.

†Calorific values in Btu/lb are based on moist, mineral-matter-free coal.

‡If agglomerating, classify in the low-volatile group of the bituminous class.

§Nonagglomerating varieties may exist in the bituminous class, most notably in the high-volatile C bituminous group.

**Coals having ≥69% fixed carbon are classified according to fixed carbon, regardless of Btu value. Coals with <69% fixed carbon but with ≥14,000 Btu/lb are classified as high-volatile A bituminous.

Huggins et al. [1985] compared the size distributions of respirable quartz at surface and underground coal mines and found that the distributions of particle sizes less than 4.2 μm were similar. The distribution of particles at surface coal mines included more quartz particles in the size range of 4.2 to 9.6 μm (2.7% versus 6.4%). The distribution of particles in both surface and underground coal mines contained <0.25% of respirable quartz larger than 9.6 μm.

Dust of high-rank coal contains a greater proportion of silica particles with uncontaminated surfaces than does dust of lower-rank coal [Kriegseis and Scharmann 1985]. Dust of high-rank coal also

Table 3–2. Coal classification: source and analyses of U.S. coal*

Classification by rank	State and county	Bed	Type of sample†	Proximate %		Ultimate %					Calorific		Value (Btu/lb)
				Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	
Meta-anthracite	Rhode Island (Newport)	Middle	1	13.2	2.6	65.3	18.9	0.3	1.9	64.2	0.2	14.5	9,310
			2	——	2.9	75.3	21.8	0.3	0.5	74.1	0.2	3.1	10,740
			3	——	3.8	96.2	——	0.4	0.6	94.7	0.3	4.0	13,720
Anthracite	Pennsylvania (Lackawana)	Clark	1	4.3	5.1	81.0	9.6	0.8	2.9	79.7	0.9	6.1	12,880
			2	——	5.3	84.6	10.1	0.8	2.5	83.3	0.9	2.4	13,470
			3	——	5.9	94.1	——	0.9	2.8	92.5	1.0	2.8	14,980
Semianthracite	Arkansas (Johnson)	Lower Hartshorne	1	2.6	10.6	79.3	7.5	1.7	3.8	81.4	1.6	4.0	13,880
			2	——	10.8	81.5	7.7	1.8	3.6	83.6	1.6	1.7	14,240
			3	——	11.7	88.3	——	1.9	3.9	90.6	1.8	1.8	15,430
Low-volatile bituminous coal	West Virginia (Wyoming)	Pocahontas No. 3	1	2.9	17.7	74.0	5.4	0.8	4.6	83.2	1.3	4.7	14,400
			2	——	18.2	76.3	5.5	0.8	4.4	85.7	1.3	2.3	14,830
			3	——	19.3	80.7	——	0.8	4.6	90.7	1.4	2.5	15,690
Medium-volatile bituminous coal	Pennsylvania (Clearfield)	Upper Kittanning	1	2.1	24.4	67.4	6.1	1.0	5.0	81.6	1.4	4.9	14,310
			2	——	24.9	68.8	6.3	1.1	4.8	83.3	1.5	3.0	14,610
			3	——	26.5	73.5	——	1.1	5.2	88.9	1.6	3.2	15,590
High-volatile A bituminous coal	West Virginia (Marion)	Pittsburgh	1	2.3	36.5	56.0	5.2	0.8	5.5	78.4	1.6	8.5	14,040
			2	——	37.4	57.2	5.4	0.8	5.4	80.2	1.6	6.6	14,370
			3	——	39.5	60.5	——	0.8	5.7	84.8	1.7	7.0	15,180
High-volatile B bituminous coal	Kentucky Western field (Muhlenburg)	No. 9	1	8.5	36.4	44.3	10.8	2.8	5.4	65.1	1.3	14.6	11,680
			2	——	39.8	48.5	11.7	3.0	4.9	71.2	1.5	7.7	12,760
			3	——	45.0	55.0	——	3.4	5.5	80.6	1.7	8.8	14,460

See footnotes at end of table.

(Continued)

Table 3–2 (Continued). Coal classification: source and analyses of U.S. coal*

Classification by rank	State and county	Bed	Type of sample†	Proximate %: Moisture	Proximate %: Volatile matter	Fixed carbon	Ultimate %: Ash	Ultimate %: Sulfur	Ultimate %: Hydrogen	Ultimate %: Carbon	Calorific: Nitrogen	Calorific: Oxygen	Value (Btu/lb)
High-volatile C bituminous coal	Illinois (Sangamon)	No. 5	1	14.4	35.4	40.6	9.6	3.8	5.8	59.7	1.0	20.1	10,810
			2	——	41.4	47.4	11.2	4.4	4.9	69.8	1.2	8.5	12,630
			3	——	46.6	53.4	——	5.0	5.6	78.6	1.3	9.5	14,230
Sub-bituminous A coal	Wyoming (Sweetwater)	No. 3	1	16.9	34.8	44.7	3.6	1.4	6.0	60.4	1.2	27.4	10,650
			2	——	41.8	53.8	4.4	1.7	4.9	72.7	1.5	14.8	12,810
			3	——	43.7	56.3	——	1.8	5.2	76.0	1.5	15.5	13,390
Sub-bituminous B coal	Wyoming (Shedian)	Monarch	1	22.2	33.2	40.3	4.3	0.5	6.9	53.9	1.0	33.4	9,610
			2	——	42.7	51.7	5.6	0.6	5.6	69.3	1.2	17.7	12,350
			3	——	45.2	54.8	——	0.6	6.0	73.4	1.3	18.7	13,080
Sub-bituminous C coal	Colorado (El Paso)	Fox Hill	1	25.1	30.4	37.7	6.8	0.3	6.2	50.5	0.7	35.5	8,560
			2	——	40.6	50.3	9.1	0.4	4.6	67.4	1.0	17.5	11,430
			3	——	44.6	55.4	——	0.5	5.0	74.1	1.1	19.3	12,560
Lignite	North Dakota (McLean)	Unnamed	1	36.8	27.8	29.5	5.9	0.9	6.9	40.6	0.6	45.1	7,000
			2	——	43.9	46.7	9.4	1.4	4.5	64.3	1.0	19.4	11,080
			3	——	48.4	51.6	——	1.6	5.0	70.9	1.1	21.4	12,230

Source: EIA [1989].

*Note: Source and analysis of coal was selected to represent the various ranks of the specifications for classification of coals by rank adopted by the American Society for Testing and Materials.

†1 = Sample as received; 2 = moisture-free; 3 = moisture- and ash-free.

contains a greater concentration of oxygen radicals when the coal is freshly crushed [Dalal et al. 1989a,b; Dalal et al. 1988; Vallyathan et al. 1988] and a greater concentration of respirable particles that have large surface areas relative to other particles in the same aerodynamic size range (i.e., plate-shaped particles) [Addison and Dodgson 1990]. Dust of anthracite coal may contain a greater concentration of respirable crystalline silica than dust of lower-rank coal because the anthracite seams are dominated by quartzite in the roof and floor [Mutmansky and Lee 1984].

The particle size distribution of dust in the mine environment includes the respirable, thoracic, and inhalable particulate mass fractions. These fractions are defined as those that are hazardous when deposited in the following regions of the human respiratory tract: in the gas-exchange region (respirable dust), anywhere within the lung airways and gas-exchange region (thoracic dust), and anywhere in the respiratory tract (inhalable dust) [ACGIH 1994]. The source of the dust generated in longwall mines influences the particle size distributions measured at various locations in the mines [Potts et al. 1990]. The proportion of thoracic dust is up to seven times greater than that of respirable dust [Potts et al. 1990]. Furthermore, the thoracic dust concentration is higher in mines using longwall methods than in mines using continuous methods.

Coal miners may be exposed to diesel emission particulates in mines where diesel-powered equipment is used. These diesel particulates are of respirable size and contribute to the total concentration of respirable dust in an occupational environment [NIOSH 1988a]. The concentration of respirable coal mine dust is determined gravimetrically, and this method does not distinguish between coal dust particulates and diesel particulates. In a study of five underground coal mines using diesel equipment, Cantrell et al. [1993] found that 27% to 62% of the measured respirable dust concentration was diesel exhaust particulates (depending on the sampling location).

3.2 COAL PRODUCTION AND MINING METHODS

As mechanization was introduced into the mines, the total number of U.S. coal miners decreased from more than 400,000 in 1950 to approximately 130,000 in 1990, and coal production increased fivefold (Table 3-3) [EIA 1989; Morgan 1975]. Table 3-3 lists coal mine production and number of miners employed from 1900 through 1990. In 1992, approximately 120,000 U.S. coal miners produced 997.5 million short tons of coal (1 short ton = 2,000 lb); 41% of the total production was from underground mines, and 59% was from surface mines [EIA 1993]. Figure 3-1 shows U.S. coal production from both surface and underground coal mines. Figure 3-2 illustrates U.S. coal production by rank (as described in Section 3.1.1).

Whether coal is mined by underground or surface methods depends on the depth of the coalbed from the surface and the character of the terrain. Underground methods are usually used to mine coalbeds deeper than about 200 feet, and surface methods are used to mine shallower coalbeds [EIA 1989].

3.2.1 Underground Coal Mining Methods

Underground mines are classified by their openings to the surface of the earth and by the coal mining method. A "shaft mine" is driven vertically into the coal deposit, while a "slope mine" is driven at

Table 3–3. Miners employed and U.S. production trends of bituminous coal and lignite in surface and underground mines, 1900 through 1990*

Year	Production (in thousands of short tons)			Number of miners employed†	Average tons per miner per day‡
	Underground	Surface	Total		
1900	212,316	NA§	NA	304,375	2.98
1901	225,828	NA	NA	340,235	2.94
1902	260,217	NA	NA	370,056	3.06
1903	282,749	NA	NA	415,777	3.02
1904	278,660	NA	NA	437,832	3.15
1905	315,063	NA	NA	460,629	3.24
1906	342,875	NA	NA	478,425	3.36
1907	394,759	NA	NA	516,258	3.29
1908	332,574	NA	NA	516,264	3.34
1909	379,744	NA	NA	543,152	3.34
1910	417,111	NA	NA	555,533	3.46
1911	405,907	NA	NA	549,775	3.50
1912	450,105	NA	NA	548,632	3.68
1913	478,435	NA	NA	571,882	3.61
1914	421,436	1,268	422,704	583,506	3.71
1915	439,792	2,832	442,624	557,456	3.91
1916	498,500	4,020	502,520	561,102	3.90
1917	546,273	5,518	551,791	603,143	3.77
1918	571,275	8,111	579,386	615,305	3.78
1919	460,270	5,590	465,860	621,998	3.84
1920	559,807	8,860	568,667	639,547	4.00
1921	410,865	5,057	415,922	663,754	4.20
1922	412,059	10,209	422,268	687,958	4.28
1923	552,625	11,940	564,565	704,793	4.47
1924	470,080	13,607	483,687	619,604	4.56
1925	503,182	16,871	520,053	588,493	4.52
1926	556,444	16,923	573,367	593,647	4.50
1927	499,385	18,378	517,763	593,918	4.55
1928	480,956	19,789	500,745	522,150	4.73
1929	514,721	20,268	534,989	502,993	4.85
1930	447,684	19,842	467,526	493,202	5.06
1931	363,157	18,932	382,089	450,213	5.30
1932	290,069	19,641	309,710	406,380	5.22
1933	315,360	18,270	333,630	418,703	4.78
1934	338,578	20,790	359,368	458,011	4.40
1935	348,726	23,647	372,373	462,403	4.50
1936	410,962	28,126	439,088	477,204	4.62
1937	413,780	31,751	445,531	491,864	4.69
1938	318,138	30,407	348,545	441,333	4.89
1939	357,133	37,722	394,855	421,788	5.25

See footnotes at end of table.

(Continued)

Table 3-3 (Continued). Miners employed and U.S. production trends of bituminous coal and lignite in surface and underground mines, 1900 through 1990*

Year	Production (in thousands of short tons) Underground	Surface	Total	Number of miners employed†	Average tons per miner per day‡
1940	417,604	43,167	460,771	439,075	5.19
1941	459,078	55,071	514,149	456,981	5.20
1942	515,490	67,203	582,693	461,991	5.12
1943	510,492	79,685	590,177	416,007	5.38
1944	518,678	100,896	619,576	393,347	5.67
1945	467,630	109,987	577,617	383,100	5.78
1946	420,958	112,962	533,922	396,434	6.30
1947	491,229	139,395	630,624	419,182	6.42
1948	460,012	139,506	599,518	441,631	6.26
1949	331,823	106,045	437,868	433,698	6.43
1950	392,844	123,467	516,311	415,582	6.77
1951	415,842	117,823	533,665	372,897	7.04
1952	356,425	110,416	466,841	335,217	7.47
1953	349,551	107,739	457,290	293,106	8.17
1954	289,112	102,594	391,706	227,397	9.47
1955	343,465	121,168	464,633	225,093	9.84
1956	365,774	135,100	500,874	228,163	10.28
1957	360,649	132,055	492,704	228,635	10.59
1958	286,884	123,562	410,446	197,402	11.33
1959	283,434	128,594	412,028	179,636	12.22
1960	284,888	130,624	415,512	169,400	12.83
1961	272,766	130,211	402,977	150,474	13.87
1962	281,266	140,883	422,149	143,822	14.72
1963	302,256	156,672	458,928	141,646	15.83
1964	321,808	165,190	486,998	128,698	16.84
1965	332,661	179,427	512,088	133,732	17.52
1966	338,524	195,357	533,881	131,752	18.52
1967	349,133	203,494	552,626	131,523	19.17
1968	344,142	201,103	545,245	127,894	19.37
1969	347,132	213,373	560,505	124,532	19.90
1970	338,788	264,144	602,930	140,140	18.84
1971	275,888	276,304	552,192	145,664	18.02
1972	304,103	291,284	595,386	149,265	17.74
1973	299,353	292,384	591,738	148,121	17.58
1974	277,309	326,098	603,406	166,701	17.58
1975	292-826	355,612	648,438	189,880	14.74
1976	294,880	383,805	678,685	202,280	14.46
1977	265,950	425,394	691,344	221,428	14.84
1978	242,177	422,950	665,127	242,295	14.68
1979	320,321	455,978	776,299	224,203	15.33

See footnotes at end of table.

(Continued)

Table 3–3 (Continued). Miners employed and U.S. production trends of bituminous coal and lignite in surface and underground mines, 1900 through 1990*

Year	Production (in thousands of short tons)			Number of miners employed†	Average tons per miner per day‡
	Underground	Surface	Total		
1980	336,925	486,719	823,644	224,938	16.32
1981	315,875	502,477	818,352	226,250	18.08
1982	338,572	494,951	833,523	214,400	18.13
1983	299,892	478,111	778,003	173,543	21.19
1984	351,474	540,285	891,759	175,746	22.26
1985	350,073	528,856	878,930	167,009	23.13
1986	359,800	526,223	886,023	152,668	25.69
1987	372,238	542,963	915,202	141,065	28.19
1988	381,546	565,164	946,710	133,913	30.57
1989	393,322	584,058	977,381	130,103	32.05
1990	424,119	601,449	1,025,570	129,619	33.25

Source: EIA [1991].

*Note: Sub-bituminous coal is included with bituminous coal. Totals may not equal sum of components because of independent rounding. Sources: 1900-1976: U.S. Department of Interior, Bureau of Mines, *Minerals Yearbooks*; 1977-1978: Energy Information Administration, *Bituminous Coal & Lignite Production and Mine Operations*; 1979-1990: *Coal Production*, various issues.

†Note: The number of "miners employed" is lower than that listed in MSHA [1991] because mines producing less than 10,000 tons are excluded here.

‡After 1978, excludes miners employed at mines that produced less than 10,000 tons.

§NA = Not available; relatively small amounts included with underground.

an angle to reach the coal. A "drift mine" is driven horizontally into coal that is exposed or accessible in a hillside. A "punch mine" is a small drift mine used to recover coal from strip-mine highwalls or from small coal deposits [EIA 1989]. Room-and-pillar mining and longwall mining are the two predominant methods.

3.2.1.1 Room-and-Pillar Mining

The most common underground coal mining method is the room-and-pillar mining system, in which the mine roof is supported primarily by coal pillars that are left at regular intervals [EIA 1989]. The rooms are the areas where the coal is mined. Either a conventional or a continuous mining method is used to extract the coal in the room-and-pillar method. Conventional mining consists of a series of operations in which the coal face is cut so that it breaks easily when blasted (with either explosives or high-pressure air). The broken coal is then loaded onto conveyers or into shuttle cars for removal to the surface. In continuous mining, the coal is extracted and removed from the coal face in one operation, using a continuous mining machine. Room-and-pillar retreat mining occurs after coal has been extracted from the rooms in a mine section; additional coal is extracted by mining the supportive pillars [EIA 1989].

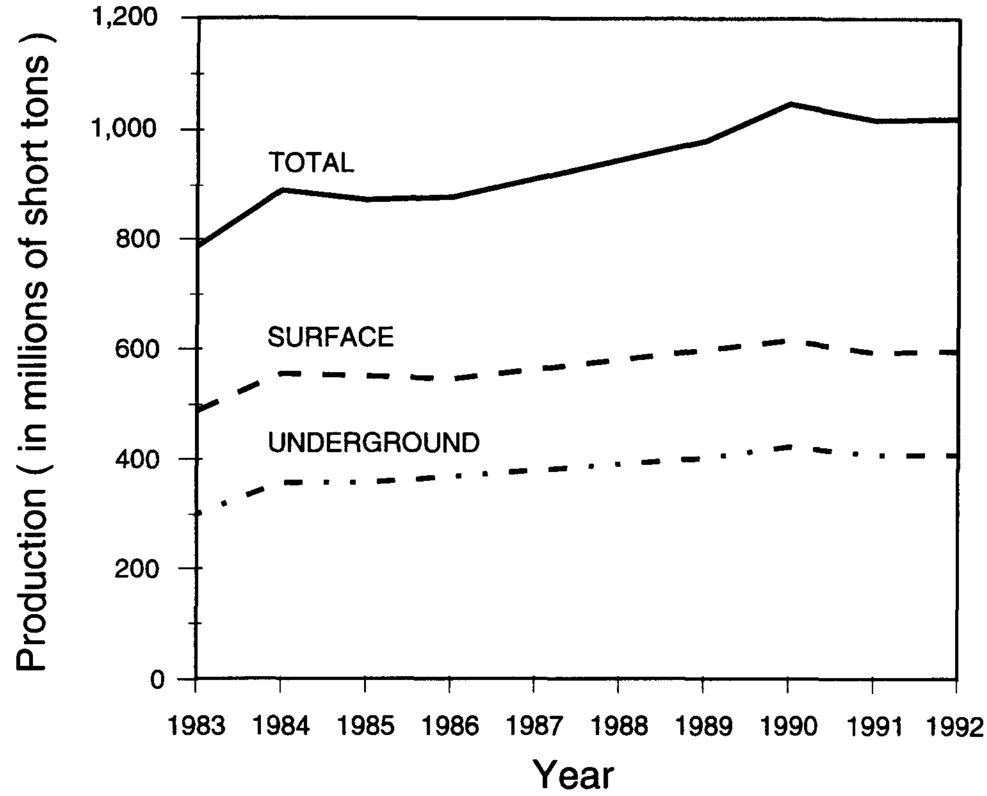

Figure 3-1. U.S. coal production in surface and underground mines, 1983–92. (Source: EIA [1993]).

3.2.1.2 Longwall Mining

Another common underground coal mining method is the longwall mining system, in which long sections of coal (also called panels) up to about 1,000 ft are removed by a cutting machine without leaving pillars of coal for support. Instead, a movable, powered roof-support system is used to support the roof in the working area. When the roof supports are moved, the area caves in and is called the gob area. After subsidence occurs, the gob area supports the overlying strata. Longwall mining is used where the coalbed is thick and generally flat, and where surface subsidence is acceptable [EIA 1989]. In 1992, mines using longwall methods accounted for 31% of the coal produced in underground coal mines [EIA 1993].

3.2.1.3 Additional Underground Coal Mining Methods

A shortwall mining system is a room-and-pillar, continuous mining system in which movable roof supports are used with a continuous miner operator. The working face is wider than in conventional or continuous sections (up to 150 ft) but smaller than in longwall mining [EIA 1989].

Hydraulic mines use high-pressure water jets to break coal from a steeply inclined, thick coalbed. The coal is transported to the surface by a system of flumes or a pipeline [EIA 1989].

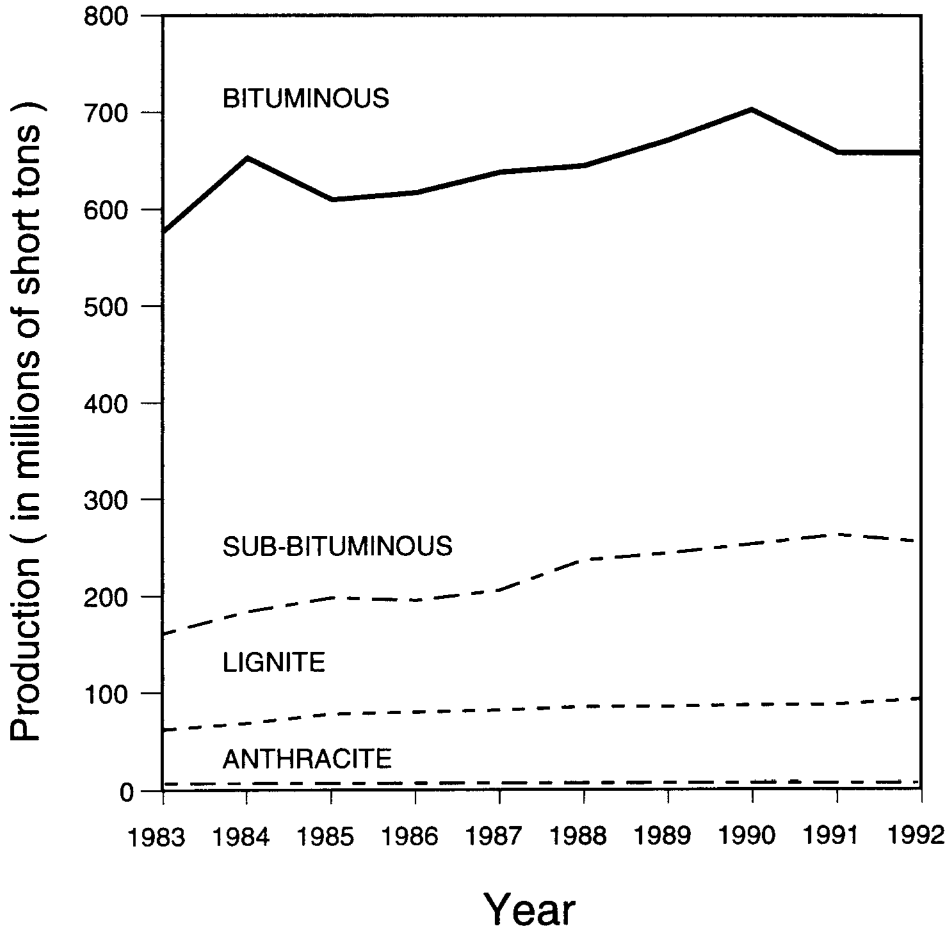

Figure 3-2. U.S. coal production by coal rank, 1983–92. (Source: EIA [1993].)

3.2.1.4 Roof Supports

The principal method of supporting the mine roof in room-and-pillar mining is through roof bolting, a process in which bolts are drilled into the mine roof to strengthen it by pulling together rock strata or by fastening weak strata to strong strata. The bolts are 2 to 10 ft long and have an expansion shell or resin grouting [EIA 1989].

3.2.1.5 Control of Gases and Airborne Dust

The principal method of controlling noxious gases and airborne respirable dust in coal mines is through mine ventilation, in which fans are used to supply fresh air and remove gases and dust from the mine. To reduce the possibility of a coal dust explosion, rock dust is sprayed in underground coal mines. Rock dust is a very fine, noncombustible material—usually pulverized limestone [EIA 1989]. Table 3-4 describes mining equipment used in underground coal mines.

3.2.2 Surface Coal Mining Methods

Strip mining, the most common type of surface coal mining, produced 99% of the coal from U.S. surface coal mines in 1992 (Table 3-5). Auger mining, coal dredging, and culm bank reclamation

Table 3–4. Glossary of underground coal mining equipment

Equipment name	Description
Coal cutting	Equipment used in conventional mining to undercut, topcut, or machine shear the coal face so that coal can be fractured easily when blasted. This equipment can cut 9-13 ft into the coal face.
Continuous auger	Augers used in mining coalbeds less than 3 ft thick. The auger machine cutting depth is about 5 ft. It usually uses a continuous conveyer belt to haul coal to the surface.
Continuous mining	Equipment used during continuous mining to cut or rip the coal from the coal face and load it into shuttle cars or conveyors. Continuous mining equipment eliminates the use of blasting and performs the functions of other machines (e.g., drills, cutting machines, and loaders). It has a turning drum with sharp bits and extracts 16-22 ft of coal before roof bolting is required. Coal is extracted at 8-15 tons/min.
Conveyer systems	Systems to carry coal. The mainline conveyer is permanently installed and carries coal to the surface. The section conveyer connects the working face to the mainline conveyer.
Face drill	Drill used in conventional mining to drill shotholes in the coalbed for explosive charges.
Loading machine	Machines used in conventional mining to scoop broken coal from the working area and load it into the shuttle car.
Longwall mining	A machine that shears coal from a long, straight coal face (up to about 600 ft) by working back and forth across the face under a movable, hydraulic-jack, roof-support system. Broken coal is transported by conveyor. Coal is extracted at 1,000 tons per shift.
Mine locomotive	A locomotive that operates on tracks and is used to haul mine cars containing coal and other material or to move personnel in mantrip cars; some can haul 20 tons at 10 mph. The locomotive is electric or battery-powered.
Ram car/scoop car	A rubber-tired haulage vehicle that is unloaded by means of a movable steel plate at rear of haulage bed.
Roof-bolting machine (roof bolter)	A machine used to drill holes and place bolts to support the mine roof. This machine can be installed on a continuous mining machine.
Scoop	A rubber-tired haulage vehicle used in thin coalbeds.
Shortwall mining machine	Usually a continuous mining machine used with a powered, self-advancing roof support system. It shears coal from a short coal face (up to 150 ft long). Broken coal is hauled by shuttle cars to a conveyer belt.
Shuttle car	A rubber-tired haulage vehicle that hauls coal to mine cars or conveyers for delivery to the surface. The car is unloaded by a built-in conveyer.

Source: EIA [1989].

Table 3-5. U.S. coal production by work location and type of coal in 1987 (operator data)
[In short tons]

Work location	Type of coal: Anthracite	Type of coal: Bituminous*	All coal
Underground mines	369,958	403,233,450	403,603,408
Surface mines:			
Strip mines	1,813,376	575,398,356	577,211,732
Auger mines	——	3,464,461	3,464,461
Culm bank	1,462,002	697,984	2,159,986
Dredge	3,466	258,438	261,904
Total (surface)	3,278,844	579,819,239	583,098,083
Total (underground and surface)	3,648,802	983,052,689	986,701,491

Adapted from MSHA [1993].
*Includes sub-bituminous and lignite.

account for the remainder. At an auger mine, coal is recovered with a large-diameter, screw-type drill that is driven up to 200 feet into a coal seam that outcrops on a hillside [EIA 1993]. Although auger mining is inefficient (only 35% of the coal is recovered), it produces coal at a lower cost in seams that are thin, dirty, isolated, or not economically recovered by other surface methods. In addition, labor costs are minimal because only the auger operators and truck drivers are needed [Porterfield and Phelps 1981]. Silty coal fines are recovered from bodies of water with coal dredges. Culm banks, the hillside where waste from anthracite mines is dumped, have been reclaimed for the fine anthracite (culm) [EIA 1993].

Strip mining is a large-scale, earth-moving process during which the overburden (or material overlying a bed of coal) is excavated and the underlying coal is removed. The working area of the strip mine is known as the pit. Overburden material excavated from the strip being mined typically is side-cast into the strip pit previously mined. The process is repeated over and over until some limit is reached (e.g., a geological limit; a property-line limit; or some economic or equipment limit) [Stefanko 1983]. The average thickness of the overburden to be removed at surface coal mines typically ranges between 30 and 60 ft. The nature of the overburden at surface coal mines is variable but is generally some combination of sandstone, shale, limestone and loose soils. The unexcavated face of exposed overburden or coal in a strip pit is referred to as the "highwall." Highwalls up to 180 ft in height have been mined [Stefanko 1983].

The process of extracting coal from a surface-coal strip mine and delivering it to consumers typically involves the following operations: (1) drilling, (2) blasting, (3) overburden excavation (stripping), (4) coal loading, (5) coal haulage, (6) reclamation, (7) coal preparation, and (8) transportation to the consumer [Stefanko 1983]. Coal preparation and transportation to the consumer are common processes to all coal mining ventures.

3.2.2.1 Drilling

Topsoil is first removed and stored for reclamation of the area to be mined. In most cases, holes are drilled in the overburden material where explosives can be placed for blasting. Drilling and blasting the overburden layer creates fragments that are easier to excavate and results in fewer problems with the operation and maintenance of excavating equipment (and thus a more rapid and economical stripping process) [Stefanko 1983].

If the overburden is greater than 50 ft thick, vertical holes for blasting are drilled in the highwall. The advantage of drilling vertical holes rather than placing explosives in a horizontal hole above the coal seam is that thicker and harder layers of overburden may be fractured without damaging the underlying coal seam. In some mines, vertical holes for blasting are also routinely drilled when the overburden is less than 50 ft thick [Stefanko 1983].

The spacing of the vertical holes in the highwall depends on factors such as the strength of the overburden material to be blasted and the type of explosive that will be used. A larger hole allows a greater amount of explosives and permits greater spacing between holes. Thus, 15-in.-diameter holes might be placed about 35 ft apart, whereas 7-in.-diameter holes might be spaced about 15 ft apart.

A stream of compressed air (referred to as "bail air") is typically injected into the drill stem and forced out through orifices in the drill bit. This air cools the drill bit's cutting points and bearings and keeps the hole being drilled free of cuttings. The injected air bails the drill cuttings up and out of the drill hole. The bail air exiting from the drill hole forms a dust cloud that may contain relatively large amounts of crystalline silica. The amount of dust from the drill hole and the amount of respirable crystalline silica in the dust cloud may fluctuate considerably, depending on factors such as geology, drilling methods, weather conditions, and water content [BOM 1986]. These factors must be considered when selecting a dust collection method for the drilling machinery.

When the overburden is less than 50 ft thick and consists of soft shale materials, an auger-type drill may be used to place long horizontal holes for blasting about 1 to 2 ft above the coal seam. This horizontal hole approach allows a large area of overburden to be blasted with a small number of holes [Stefanko 1983].

3.2.2.2 Blasting

The next step in the work process is to place explosives in the holes that have been drilled in the overburden. Ammonium nitrate (94%) with fuel oil (6%) (generically referred to as ANFO) is the most commonly used explosive in surface coal mining. This explosive is detonated by using special cast primers that are in turn ignited by blasting caps. A detonating fuse is typically used with a highly explosive core of pentaerythritol tetranitrate (PETN). Millisecond-delay elements permit delays between detonation of individual holes to improve fragmentation [Stefanko 1983].

3.2.2.3 Overburden Excavation (Stripping)

The blast causes some of the overburden to fall into the pit. However, most of the overburden is retained in the highwall area as fragmented material. Several different types of equipment may be used to remove the fragmented overburden material. Descriptions of this equipment are provided in Table 3-6. When there are small amounts of overburden, bulldozers, scrapers, and front-end loaders may be used. When there are large amounts of overburden, power shovels may be operated in the pit, or draglines may be operated from on top of the overburden beside the pit. In addition, bucket-wheel excavators are used at a few surface coal mines in the United States [Stefanko 1983].

The overburden removed in gaining access to the coal is called the spoil. The excavated overburden from the pit and the highwall are typically discharged (spoiled) at the side of the pit opposite the highwall. The process builds up mounds of loose material that are collectively called the spoil bank [Stefanko 1983].

3.2.2.4 Coal Loading

Following overburden removal, the exposed coal seam is excavated and loaded onto trucks by power shovels or by front-end loaders, either rubber-tired or track-mounted. In some mines, coal excavation may include drilling and blasting (so that the coal can be excavated with relative ease) or using a ripper to loosen it [Stefanko 1983].

3.2.2.5 Coal Haulage

In the United States, large, off-highway diesel or electric trucks are typically used in surface coal mines to transport coal from the pit to the coal preparation plant or a railroad loading siding. Eastern and midwestern strip mines tend to employ rear-dump units (35- to 85-ton capacity) because this type of truck maneuvers well in compact pit operations, has good traction capabilities, and can cope with the steep ramps and sharp haul road turns. Westernstrip mines tend to use drop-bottom tractor-trailer units (100- to 200-ton capacity) because the pits are larger, the haul distances are longer, the ramps have gentler grades, and traction is not a problem [Stefanko 1983].

3.2.2.6 Reclamation

The Surface Mining Control and Reclamation Act of 1977 [30 USC 1201 et seq.] and State laws require reclamation of a surface mine work area after coal has been extracted. Reclamation enables the land to be used in the future for some other purpose; it also minimizes wind and water erosion, and it is more aesthetically acceptable. The reclamation process includes putting the overburden back in the same stratigraphic layer in which it originally existed, providing drainage, replacing topsoil, recontouring, and reestablishing permanent vegetation [Stefanko 1983].

3.2.2.7 Coal Preparation

Most of the coal produced in the United States undergoes some degree of processing or preparation before it is used. The amount of preparation depends on the specifications of the customer. About two-thirds of the coal shipped to electric power plants from eastern mines is cleaned, whereas most of the coal shipped to electric utilities from western mines is only crushed and screened to facilitate handling and to remove any extraneous material [EIA 1989].

Table 3–6. Glossary of surface coal mining equipment

Equipment name	Description
Auger	A large-diameter (16- to 48- in.) screw drill that cuts, transports, and loads overburden or coal onto vehicles or conveyors.
Bucket wheel	A boom-mounted, rotating, vertical wheel with buckets on its periphery used to load an internal conveyor network that discharges away from the digging area.
Bulldozer	A tractor with a vertically curved steel blade mounted on the front end. The blade is held at a fixed distance by arms secured on a pivot or shaft near the horizontal center of the tractor.
Dragline	Excavating equipment that can cast a cable-hung bucket a considerable distance. The dragline can collect material by pulling the bucket toward itself on the ground with a second cable, elevate the bucket, and dump the material in a pile.
Front-end loader	A tractor-loader with a digging bucket mounted and operated on the front end.
Power shovel	An excavating and loading machine with a digging bucket at the end of an arm suspended from a boom that extends crane-like from the part of the machine that houses the power plant.
Ripper	A steel accessory (tooth-shaped) that is mounted or towed by a bulldozer and is used in place of blasting for loosening compacted materials.
Scraper	A steel tractor that can dig, haul, and grade. A scraper has a cutting edge, a carrying bowl, a movable front wall, and a dumping or ejecting mechanism.

Sources: EIA [1989]; Skelly and Loy [1979].

Cleaning upgrades the quality and heating value of coal by (1) removing or reducing the amount of pyrite, rock, clay, or other ash-producing material, and (2) removing any materials mixed with the coal during mining, such as wire and wood. Coal cleaning is based on the principle that coal is lighter than rock and other impurities mixed or embedded in it. The impurities are separated by various mechanical devices using pulsating water current, rapidly spinning water, and liquids of different densities (dense media). Finely sized coal is cleaned by froth flotation. In this process, the coal adheres to air bubbles in a reagent and floats to the top of the washing device, whereas the refuse sinks to the bottom [EIA 1989]. Exposure to respirable dust at preparation plants may occur (1) during loading, unloading, and moving coal, (2) when processing equipment is cleaned, (3) when heavy media (e.g., magnetite) are added to liquid slurry to achieve a desired specific gravity in a cyclone, and (4) when refuse is transported [Llewellyn et al. 1981].

3.2.2.8 Transportation to Consumers

Coal may be delivered to consumers by several different modes of transportation, including railroads, barges, ships, trucks, conveyors, and slurry pipelines. Railroads deliver nearly 70% of the coal distributed to domestic customers and export terminals. More than half of all railroad coal shipments are made by unit trains (a train that is dedicated to coal transportation and that carries coal from a specified loading facility directly to a specified customer) [EIA 1989].

3.3 NUMBER OF MINERS POTENTIALLY EXPOSED IN U.S. COAL MINES

In 1992, an estimated 118,733 miners were employed in U.S. underground and surface coal mines, including 1,991 miners at anthracite coal mines and 116,742 miners at bituminous coal mines [MSHA 1993]. Of the 118,733 miners, 54% (64,481) were employed at underground coal mines, 34% (39,882) were employed at surface coal mines, and 12% (14,370) were employed at coal preparation plants or other operations [MSHA 1993].

3.3.1 Occupational Exposures in U.S. Coal Mines

MSHA requires that respirable dust samples be collected by mine operators to determine compliance with the PELs for respirable coal mine dust and respirable crystalline silica [30 CFR 70.201-70.220; 71.201-71.220]. MSHA also conducts periodic mine inspections and respirable dust sampling [MSHA 1989a]. From 1988 through 1992, approximately 350,000 respirable coal mine dust samples were collected in underground mines by both MSHA inspectors and coal mine operators, and approximately 19,700 samples were analyzed for respirable crystalline silica. In surface coal mines, approximately 60,600 respirable coal mine dust samples were collected, and approximately 4,100 samples were analyzed for respirable crystalline silica. Tables A-1 through A-3 in Appendix A provide the number of respirable coal mine dust samples collected by MSHA inspectors and mine operators and the number of samples analyzed for respirable crystalline silica each year from 1988 through 1992. Also listed for each year is the number of producing mines.

3.3.1.1 Exposures to Respirable Coal Mine Dust

Tables A-4 through A-7 list the concentrations of respirable coal mine dust in underground and surface coal mines. These concentrations are based on samples collected by MSHA inspectors and coal mine operators from 1988 to 1992. Samples for underground occupations (Tables A-4 and A-5) show that average concentrations of respirable coal mine dust from 1988 to 1992 were below 2.0 mg/m^{3}* for most occupations. However, even occupations with average concentrations below 2.0 mg/m^3 had up to 42% of individual samples exceeding 2.0 mg/m^3. It should be noted that compliance with the MSHA PEL is currently determined by an arithmetic average of five samples collected during a normal production shift or work shift [30 CFR 70.207(a), 70.2(k)]. Thus, the occurrence of individual samples that exceed the MSHA PEL is not an indication that a mine is out of compliance. Another current regulation is that sampling devices are operated for a full shift or for 8 hr, whichever is less [30 CFR 70.201(b), 71.201(b)]. Thus, if actual work shifts exceed 8 to 10 hr/day and 40 hr/week, the measured concentrations would underestimate actual exposures. Area sampling results for respirable coal mine dust in underground mines from 1988 to 1992 are summarized in Table A-12.

Samples for surface coal mine and preparation plant occupations (Tables A-6 and A-7) show that the average concentrations of respirable coal mine dust from 1988 to 1992 were below 2.0 mg/m^3 for all occupations. In general, less than about 16% of individual samples exceeded 2.0 mg/m^3.

*Based on the current MSHA sampling method (Section 5.1), including use of the MRE conversion factor of 1.38 and a sampling flow rate of 2.0 L/min.

3.3.1.2 Exposures to Respirable Crystalline Silica

The average concentration of respirable crystalline silica from 1988 to 1992 was greater than the MSHA PEL of 0.1 mg/m^3 for up to 7 underground occupations and greater than the NIOSH REL of 0.05 mg/m^3† for more than 20 underground occupations (Tables A-8 and A-9). Among those occupations with *average* exposures to respirable crystalline silica less than or equal to the MSHA PEL of 0.1 mg/m^3, approximately one-third of all individual samples exceeded 0.1 mg/m^3. Area sampling results for respirable crystalline silica in underground coal mines from 1988 to 1992 are summarized in Table A-13.

In surface operations, the average concentration of respirable crystalline silica was greater than the MSHA PEL of 0.1 mg/m^3 for all occupations combined (see MSHA code 999, summary for valid occupations, in Tables A-10 and A-11). The average concentration of respirable crystalline silica exceeded the NIOSH REL of 0.05 mg/m^3 for up to 13 surface occupations. Exposures of drillers and driller helpers to respirable crystalline silica are of particular concern, with average concentrations from 1988 to 1992 ranging from 0.15 to 0.51 mg/m^3, and with up to 70% of all samples exceeding the MSHA PEL and up to 82% exceeding the NIOSH REL. Methods for controlling exposures during overburden drilling at surface coal mines are provided in Appendix D.

Only those samples with at least 0.5 mg of respirable coal mine dust are currently analyzed for respirable crystalline silica [Niewiadomski et al. 1990]. Therefore, the estimated values listed in Tables A-8 through A-11 for both the mean concentration of respirable crystalline silica and the percentage of samples exceeding specified concentrations may be biased toward higher concentrations and higher percentages.

Miners who show radiographic evidence of simple CWP category 1 or greater have the option to transfer to another position in the mine where the concentration of respirable dust is either <1.0 mg/m^3 (if attainable) or the lowest attainable concentration below 2 mg/m^3 [30 USC 843(b); 30 CFR 90]. Appendix B provides the respirable coal mine dust and respirable crystalline silica exposures of miners who elected to transfer under the provisions of 30 CFR 90. Tables B-1 through B-4 show that the average respirable coal mine dust concentrations for some occupations exceeded 1 mg/m^3. Among surface occupations, all of the average concentrations of respirable coal mine dust and most of the individual samples were below 1 mg/m^3. Exposure to respirable crystalline silica remains a concern for miners who elect to transfer [30 CFR 90]; Tables B-5 and B-6 show that exposures for some occupations (particularly roof bolters) exceeded the MSHA PEL of 0.1 mg/m^3. Furthermore, the average concentration of respirable crystalline silica for all underground occupations combined (Part 90 miners) exceeded the NIOSH REL of 0.05 mg/m^3 (Table B-5).

3.3.2 Occupational Exposures in Small Mines

Nearly 3,000 small coal mines are in operation in the United States, and more than 40,000 miners are employed at these small mines [MSHA 1994]. A small mine is one with fewer than 50 employees. Small mines are often operated by contract production operators and are part of a larger economic entity. Most small mines are located in the Appalachian regions of eastern Kentucky,

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†Based on a sampling flow rate of 1.7 L/min and no use of the MRE conversion.

southern West Virginia, and southwestern Virginia. Sixty-five percent of the small mines are surface mines.

The incidence rates of fatalities and serious injuries have been higher in small mines than in larger mines [MSHA 1994]. The prevalence of simple CWP has also been found to be higher in small mines [Linch 1994]. Exposures to respirable coal mine dust in small coal mines do not exceed those in larger coal mines [Linch 1994], but there is concern that sampling procedures and inspections may be inadequate and that extended work schedules may result in exposures that exceed those reported [MSHA 1994]. In April 1994, MSHA convened a conference to focus on ways to improve safety and health in small mines [MSHA 1994].